THE GEOLOGY OF THE RÍO BENI: FURTHER EVIDENCE FOR HOLOCENE FLOODING IN AMAZONIA

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ABSTRACT. Quaternary sediments exposed in outcrops along the Río Beni, Bolivia, were deposited in two widely separated depositional realms. The Sierra Realm extends northeastward from the front range of the Andes for 15–30 km, whereas the Monte Realm encompasses all of the northernmost lowlands of Bolivia. In both depositional realms the same stratigraphic sequence occurs: a lower unit of clays with numerous channel-fill deposits at its base, capped by two upper units of clayey silts and fine sands. The sediments of the Sierra Realm were derived from the Bolivian Andes; by all indications they were deposited contemporaneously with those of the Monte Realm. The strata within the Monte Realm are correlated with those to the northwest along the Río Acre and Río Juruá, demonstrating that the deposits cropping out along the lower Río Beni represent the easternmost extension of the Iñapari Formation, a series of Holocene alluvial deposits derived from the Peruvian Andes. The geological deposits of northern Bolivia provide supporting evidence for the hypothesis of large-scale Holocene flooding and deposition in southwestern Amazonia. A catastrophic flood resulting from the sudden draining of glacial Lake Titicaca is proposed to account for some of this flooding and several geological features found in southwestern Amazonia.

RESUMEN. Los sedimentos cuaternarios expuestos en los estratos a lo largo del río Beni, Bolivia, fueron depositados por dos amplias y separadas corrientes deposicionales. La "Corriente de la Sierra" que se extiende al noreste, desde el frente de la Cordillera de los Andes por 15 a 30 kilómetros y la "Corriente del Monte" que abarca la parte septentrional de las tierras bajas de Bolivia. En ambas corrientes deposicionales se presenta la misma secuencia estratigráfica: una unidad inferior de arcillas con numerosos canales basales y dos unidades superiores compuestos por arcillas limosas y arenas finas. Los sedimentos de la Corriente de la Sierra derivan de los Andes bolivianos, por todas las evidencias ellos fueron depositados contemporaneamente a aquellos de la Corriente del Monte. Los estratos de la Corriente del Monte son correlacionados con los descritos para el río Acre y río Juruá al noroeste de Bolivia, de manera que los depósitos que se presentan aguas abajo del río Beni representan la extensión más oriental de la Formación Iñapari, una serie de depósitos aluviales holocénicos derivados de los Andes peruanos. Los depósitos geológicos septentrionales de Bolivia son las evidencias que sustentan la hipótesis de una inundación a gran escala durante el holoceno y la deposición de sedimentos en la Amazonía meridional. Una inundación catastrófica resultante del repentino drenaje del lago glacial Titicaca es propuesto para explicar varios rasgos geológicos encontrados en el sudoeste de la Amazonía.

INTRODUCTION

The Amazon Basin and its neighboring lowlands have yet to receive the in-depth, rigorous geological research warranted a region so important to the South American continent, and indeed, to the world. Occupying an area of over 1,800,000 km², these vast lowlands are the subject of only a small number of modern publications that discuss their geological features and sediments (e.g., see citations in Petri and Fúlfaro, 1983). Almost all recent geological research has been directed toward the discovery and exploitation of petroleum resources; without recognized economic importance Quaternary geology has been very neglected. Aside from economics, there are clear reasons for the lack of geological research in Amazonia. The region is quite inaccessible, and river travel is the only means of movement over vast areas. Furthermore, the tropical forest, the largest such forest in the world, provides an almost complete cover of thick vegetation that limits the study of surficial deposits to river cutbanks and well cores. Nevertheless, geological research can and must be carried out in these still remote lands in order that a solid core of geological data is developed upon which future planned developments within the region can be based. This is particularly critical because preliminary data indicate that both

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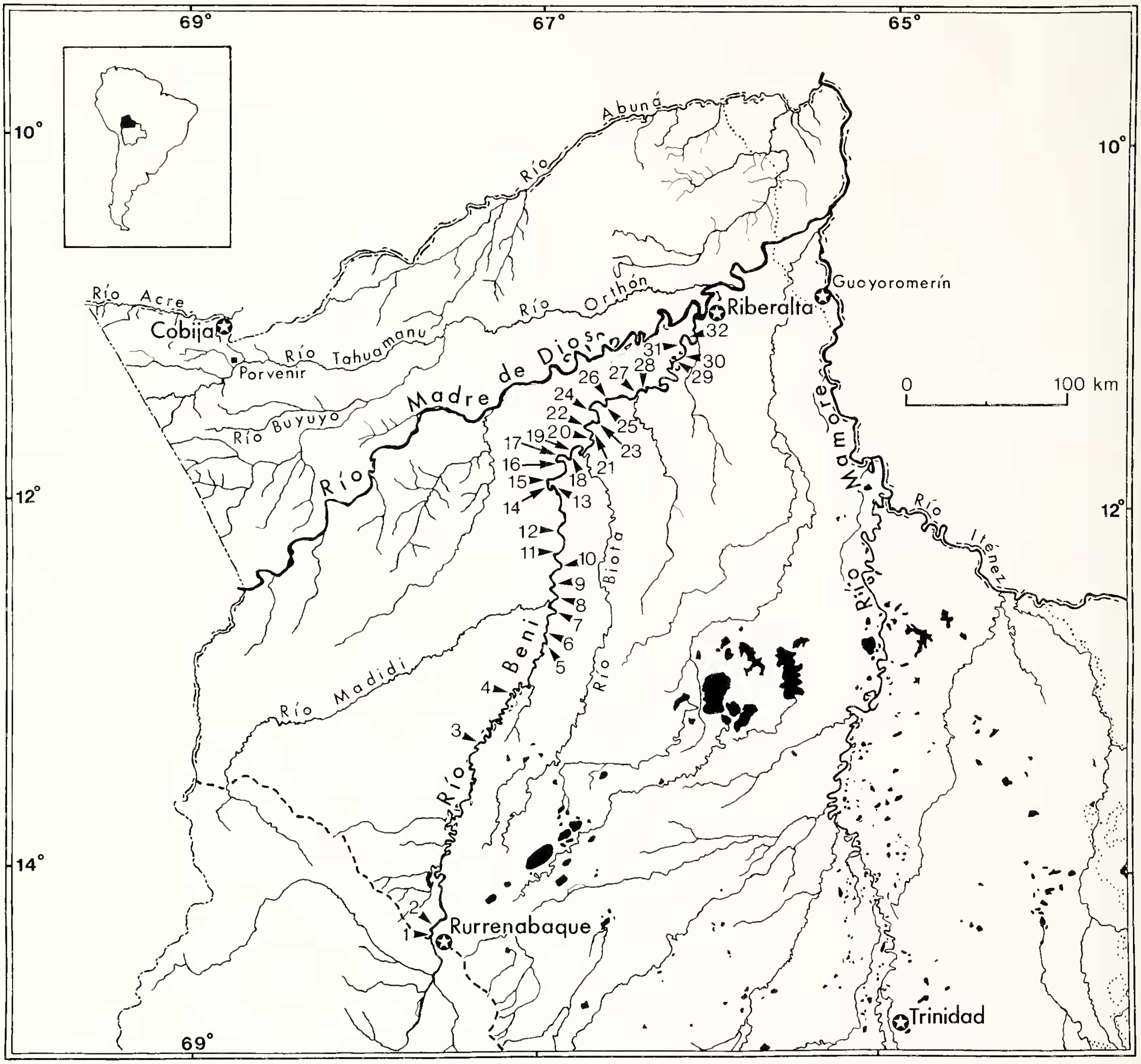

Figure 1. Map of northern Bolivia showing the major outcrops along the Río Beni, with distances in river-km (Servicio de Hidrografia Naval, 1969) from Rurrenabaque: **1.** Buena Vista (11); **2.** Altamarani (17); **3.** San Pablo (227); **4.** San Roque (281); **5.** Santa Catalina (345); **6.** Guayaros (355); **7.** Candelaria (372); **8.** Cavinas (385); **9.** Carmen Alto (395); **10.** Centro Navidad (410); **11.** Barraca Rosario (421); **12.** Fortaleza (437); **13.** Ciudad California (465); **14.** Etea (473); **15.** Florencia (481); **16.** Remanso (496); **17.** Santa Elena (503); **18.** Santa Rosa (510); **19.** Sabacón (515); **20.** Mamorébey (544); **21.** San Manuel (548); **22.** San Martin (557); **23.** Peña Amarilla (569); **24.** Maracaibo (581); **25.** Concepción (595); **26.** San Miguel (601); **27.** Brisa (621); **28.** Barrio Lindo (627); **29.** Palermo (694); **30.** Candelaria (702); **31.** Libertad (720); **32.** Puerto Gonzelo Moreno (728); Riberalta (758). The dashed line (---; lower left) indicates the northeastern limit of the front range of the Andes, while the dotted line (.....; upper and lower right) indicates western limit of Brazilian Shield. Base map: Mapa Geológico de Bolivia, 1978, Yacimientos Petroliferos Fiscales Bolivianos and Servicio Geológico de Bolivia, La Paz.

long-held assumptions (e.g., Abelson, 1983) and newly popular hypotheses (e.g., see papers in Duellman, 1979; Prance, 1982) concerning the late Cenozoic history of Amazonia require reevaluation.

The alluvial deposits covering the vast region of the Amazon Basin and its neighboring lowlands have always been considered to be Pliocene to Pleistocene in age (e.g., Jenks, 1956; Ruegg, 1956; Kummel, 1948; ONERN, 1977; Petri and Fúlfaro, 1983; RADAMBRASIL, 1976, 1977). Recently, however, Campbell and Frailey (1984, in press) have demonstrated that the alluvial deposits cropping out along the Río Acre in southwestern Amazonia and, by correlation, similar deposits cropping out along the upper Río Juruá about 500 km northwest of the Río Acre, are Holocene in age. Alluvial deposits forming three distinct units rest upon deeply weathered Tertiary deposits along both of these rivers. A characteristic basal clay-pebble conglomerate containing reworked Tertiary vertebrate fossils and fossil wood is a widespread, but discontinuous, feature of these Holocene deposits. The deeply weathered Tertiary deposits are indicative of late Pleistocene soil profiles, the upper portions of which were removed prior to the deposition of the Holocene deposits.

To account for this blanket of Holocene sediments occurring over such a broad area, Campbell and Frailey (1984, in press) proposed that massive flooding resulted from the melting of the Andean glaciers at the end of the Pleistocene. They suggested that this flooding scoured the uppermost soil zones developed on Tertiary strata in the region, depositing the clay-pebble conglomerate in its wake. Further, they proposed that this massive early flooding was followed by three distinct cycles of deposition and erosion, the last period of erosion being that which is underway today. Dates of about 5000 yr B.P. and about 2800 yr B.P. were proposed to mark the ends of the first two periods of deposition.

To determine if similar deposits of comparable age and lithology occurred farther to the south, a geological survey crossing the northern lowlands of Bolivia from the front range of the Andes to the Brazilian Shield was executed via the Río Beni in July 1983. We reasoned that if three distinct cycles of Holocene deposition and erosion had occurred over wide areas of the Amazonian lowlands, evidence for these cycles should exist in the alluvial deposits extending eastward from the front range of the Andes. We conducted the survey by means of boat travel from Rurrenabaque, at the base of the front range (Fig. 1), to Riberalta, at the confluence of the Río Beni and Río Madre de Dios. The transect was completed by road between Riberalta and Guayaramerín, the latter a town on the Bolivian–Brazilian border.

The survey was hampered by very unusual heavy rains that fell in eastern Bolivia during the dry season of 1983, a local expression of worldwide climatic anomalies occurring at that time (Philander, 1983a, b; Gill and Rasmusson, 1983). These rains maintained the level of the Río Beni over 2 m higher than what is normal for July, possibly preventing us from observing the contact between the basal Quaternary deposits and the underlying Tertiary strata. In other areas of

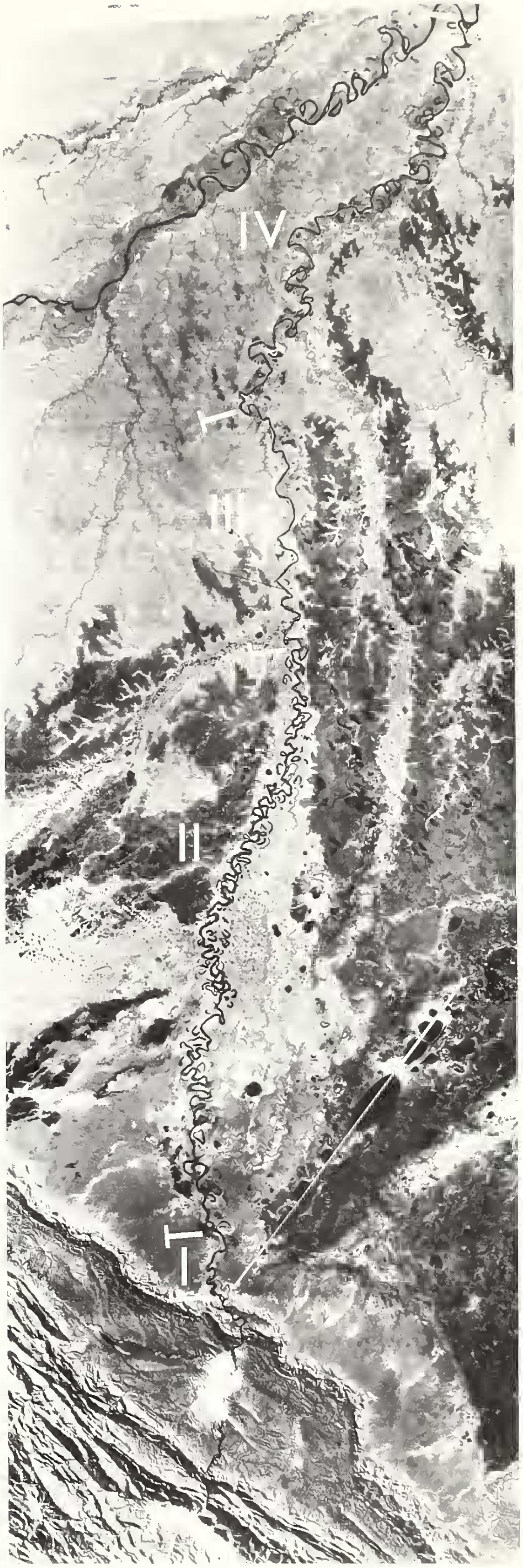

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Figure 2. Satellite photo mosaic showing the course of the Río Beni from the Andes to Riberalta. The four regions of the river discussed in the text are indicated. Northeast of the front range of the Andes the light gray indicates areas slightly higher and better drained than the areas of dark gray to the south. The light gray bands bordering the rivers cutting through areas of dark gray indicate significant natural levees. The white line running through the chain of lakes points directly toward the point of exit of the main channel of the Río Beni from the front range of the Andes.

southwestern Amazonia this contact, if visible at all, is seen only when the rivers are at their lowest level during the dry season. In addition, a newly deposited, deep layer of mud made it very difficult, and in places impossible, to reach the outcrops. All figures of outcrop height are relative to the level of the river at the time we left Rurrenabaque, but unfortunately this level could not be fixed relative to a known datum. The fluctuating level of the river, which rose and fell over 1 m during the course of our trip as the consequence of a single storm, endows all following figures of outcrop height with a degree of error.

GEOLOGY

The eastern lowlands of Bolivia extend through the country from its northern to its southern borders. The Andes flank the lowlands on the west, with the front range in places rising abruptly thousands of meters above the flat, swampy plains. To the east the lowlands are bordered by the low sierras of the Brazilian Shield, and many scattered remnants of the Brazilian Shield stand isolated, surrounded by Quaternary deposits. All of the rivers draining the northern two-thirds of the Bolivian lowlands converge upon the Río Madre de Dios and exit Bolivian territory at its northeastern corner, crossing over the crystalline rocks of the Brazilian Shield. Because the terrain is so flat (e.g., the elevation of Rurrenabaque is 227 m; Cobija, 202 m; Trinidad, 155 m; and Riberalta, 135 m (Instituto Nacional de Estadistica, 1982), the discharge from the rivers draining the eastern cordillera of the Andes cannot be constrained to existing river channels and the lowlands are consequently regularly inundated by seasonal floods. (Note: the Servicio Nacional de Meteorología de Bolivia (in Montes de Oca, 1983) gives the elevations as: Rurrenabaque, 227 m; Cobija, 280 m; Trinidad, 236 m; and Riberalta, 172 m.) The southern one-third of the eastern Bolivian lowlands is, for the most part, an extensive area of swamplands with no external drainage.

The geological deposits cropping out along the Río Beni were formed in two different depositional realms about 180 air-km apart. We consider a depositional realm to be a geographically well-defined area within which deposition of sediments occurred during a specified time, in this case, the Quaternary. The first depositional realm we crossed extends northeastward from the front range of the Andes and is referred to hereafter as the Sierra Realm because of its proximity to the mountains. The second depositional realm encompasses all of the northernmost Bolivian lowlands and is referred to hereafter as the Monte Realm because of its thick cover of tropical forest. The course of the Río Beni east of Rurrenabaque includes about 15 air-km in the Sierra Realm and about 210 air-km in the Monte Realm. The two depositional realms stand out on satellite photographs (Figs. 2, 3) as light gray areas, in contrast to the dark gray of the intervening area which is lower in elevation. The differing shades of gray result from different vegetation types; the lighter grays indicate forests, the darker grays indicate wet savannas or swamplands. The strips of light gray that cross the dark gray areas, and within which lie the river channels, reflect the higher topography of the natural levees bordering the rivers.

In the 180-air-km interval between the two depositional realms only two small outcrops of possible Quaternary deposits were seen. Everywhere else in this interval the banks of the Río Beni are formed exclusively of Recent alluvium with a relatively constant thickness of 2 m. At San Pablo and San Roque (Fig. 1, locs. 3, 4) unstratified, variegated, red, green, and gray clays extended to about 2–3 m above the waterline. These clays are capped by about 1 m of Recent alluvium that forms a flat terrace.

THE SIERRA REALM

The deposits of the Sierra Realm were all derived from the Bolivian Andes immediately to the west. Included are the alluvial fan deposits formed of sediments coming directly off the eastern slopes of the front range and the deposits brought from the valleys of the eastern Andes through the front range by the Río Beni and Río Madidi.

There are only two outcrops along the Río Beni within the Sierra Realm that provide good sections: at Buena Vista and Altamarani, 11 and 17 river-km, respectively, from Rurrenabaque (Fig. 1, locs. 1, 2). The most complete section extends from Altamarani downstream for about 1 km to just above the confluence with the Río Tuihuapa. About 9–10 m thick at its highest, the section consists of three distinct units of unconsolidated alluvial sediments (Fig. 4). The basal unit, Member A, consists of poorly stratified gray, green, and yellow variegated clays about 2 m thick. Channel-fill conglomerates of small pebbles occur in the lower part of this unit. A sharp contact separates these clays from the overlying unit (Member B) of blocky, reddish clayey-silts about 3 m thick, the top of which is marked by two prominent and other smaller dark-gray paleosols. The uppermost unit, Member C, consists of about 4–5 m of fine silts capped by a 20–30-cm-thick layer of black soil.

The same three units occur in the Buena Vista section, but Member C is much thinner, presumably through loss by erosion. In addition, a cobblestone conglomerate passes under Member A at the upriver end of the Buena Vista section. Multiple paleosols are also present at the top of Member B at Buena Vista.

Both the Buena Vista and Altamarani sections occur on the north side of the river, and the terrain extending back from the river's edge is essentially flat. Except for one other outcrop upriver from Buena Vista, also on the north side of the river, the banks of the Río Beni within the Sierra Realm consists of Recent alluvium, about 2 m thick. The third outcrop mentioned did not provide a clear section and was only about 8 m thick. No clastic sediments coarser than sand occur downriver from the Buena Vista section.

For the size of the area drained by the Río Beni and its tributaries, a mountainous region of approximately 67,000 km^2 with peaks up to 7010 m elevation, the quantity of Quaternary river deposits lying east of the front range is remarkably small. Indeed, as can be noted on satellite pho-

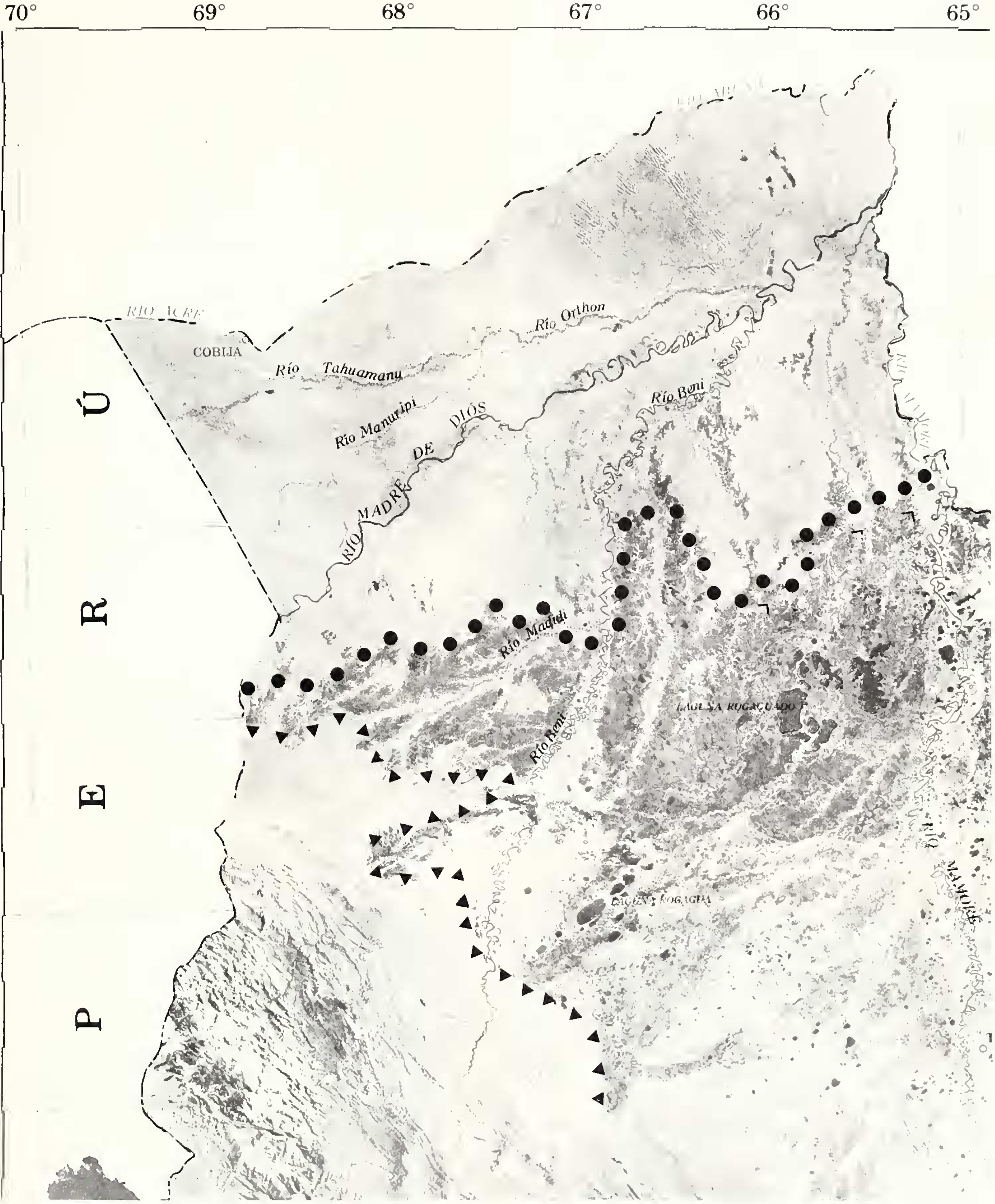

Figure 3. Satellite photo mosaic of northern Bolivia showing the extent of the Sierra and Monte Depositional Realms, the courses of the major rivers, and the linear series of rectangular lakes extending northeastward from Rurrenabaque. The line of dots delimits the southern extent of the Monte Depositional Realm and the line of triangles indicates the eastern limit of the Sierra Depositional Realm. From: Foto-Mosaico Landsat de Bolivia, Edición 1-P.E.B., 1975, Servicio Geológico de Bolivia. Reproduced by permission of the Servicio Geológico de Bolivia.

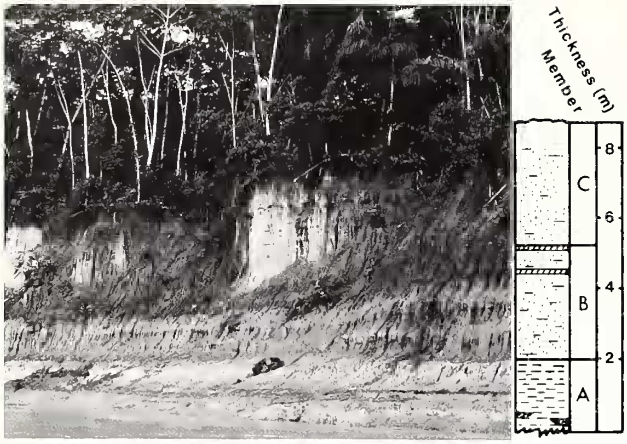

Figure 4. The geological section at Altamarani (Fig. 1, loc. 2) is composed of three units. The lower unit (Member A) of channeled, variably stratified clays is capped by two upper units (Members B and C) of variably stratified, blocky silts, and fine sands. The two dark bands at the top of Member B are prominent paleosols.

tographs (Figs. 2, 3), the eastward extent of the deposits left by the Río Beni at its point of exit from the front range appears to be less than that of the alluvial fan deposits immediately north and south of the river that represent deposition of sediments derived solely from the eastern slopes of the front range. We will return to this absence of expected alluvial deposits later.

THE MONTE REALM

Trending north-northeastward, the Río Beni cuts through the Monte Realm from Santa Catalina (Fig. 1, loc. 5) to its confluence with the Río Madre de Dios at Riberalta. The total areal extent of the Monte Realm is unknown, although from satellite photographs (Fig. 3) it may be inferred to cover approximately 90,000 km^2 in Bolivia. The terrain immediately to the south of the Monte Realm is 15–20 m lower in elevation, flat, swampy, and frequently inundated during the annual rainy season. These areas of lower elevation appear dark on the satellite photos (Figs. 2, 3), in contrast to the lighter color of the better drained Monte Realm.

Outcrops are relatively common along the Río Beni from Santa Catalina to Riberalta, and the geologic sections are all quite similar (see Fig. 1 for major localities). The generalized section (Figs. 5, 6) is composed of three units of unconsolidated alluvial sediments, each similar in lithology to the corresponding unit seen in the Sierra Realm. The basal unit, Member A, consists of about 3–5 m of variably stratified, relatively pure, red, gray, green, and yellow variegated clays. In the lower part of these clays occur many channel-fill deposits composed of fine-grained, well-sorted sands, silts, and clay-ball conglomerates. The size of the multicolored clay balls in the conglomerate range from less than 10 mm to over 250 mm, and they occur both well sorted or poorly sorted, and with or without a silt or sand matrix (Fig. 7a).

Layers of hematite 3–6 cm thick are a distinctive feature of Member A. These occur between the channel deposits in the lower part of the unit and also at the contact with silts and sands of the overlying member. The layers are convoluted in many places (Fig. 8a, b), and represent groundwater deposition of hematite at the contact between differing lithologies.

Members B and C, each about 4–8 m thick, are similar lithologically, being composed of silts and fine sands. In many outcrops the contact between them may be readily distinguished only by sharp color differences (Fig. 5b), but at other localities a distinct disconformity is visible (Figs. 5a, 6). At some outcrops, such as at Ciudad California, channel deposits of sands and clay-ball conglomerates can be seen at the top of Member B. When these channel deposits occur, local layers of hematite may also be present as in Member A, although they are usually much thinner.

The first complete section encountered in the Monte Realm (Santa Catalina, Fig. 5a) differed from those farther down-

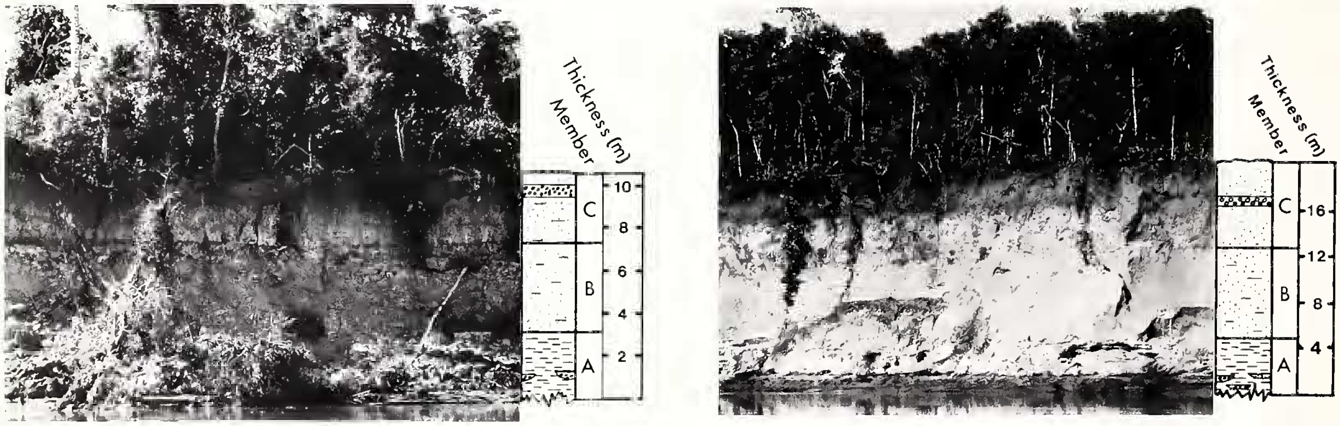

Figure 5. Two geological sections along the Río Beni in the Monte Depositional Realm. **a**(left). Santa Catalina (Fig. 1, loc. 5). **b.** Cavinas (Fig. 1, loc. 8). Both sections show the hematitic concretionary zone in the B zone of the soil profile developed on Member C. The higher clay content of the sediments at Santa Catalina is reflected in the surface texture of the outcrop.

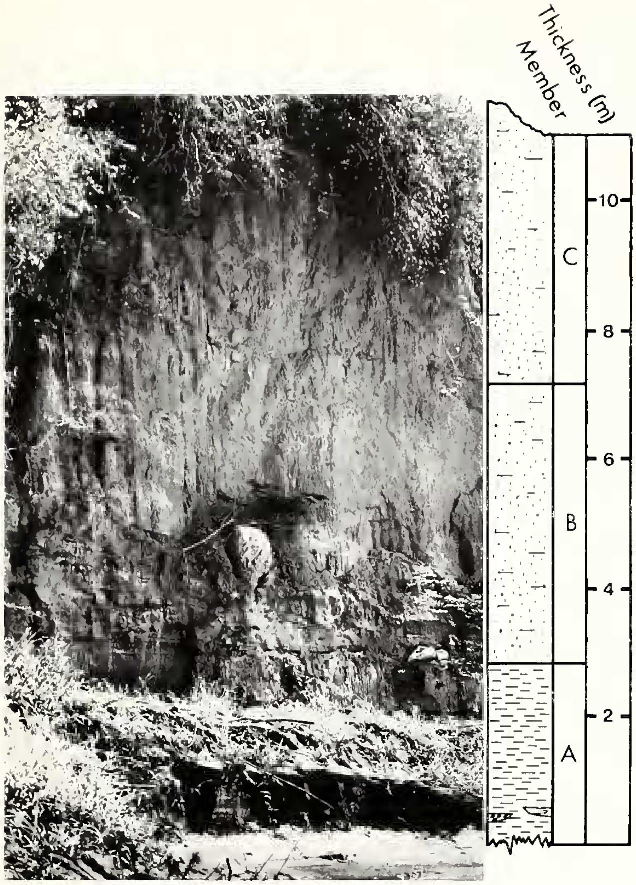

Figure 6. A partial view of the section at San Martin (Fig. 1, loc. 22) clearly shows the two contacts separating the three members of the Iñapari Formation. At this locality the base of Member B shows good stratification.

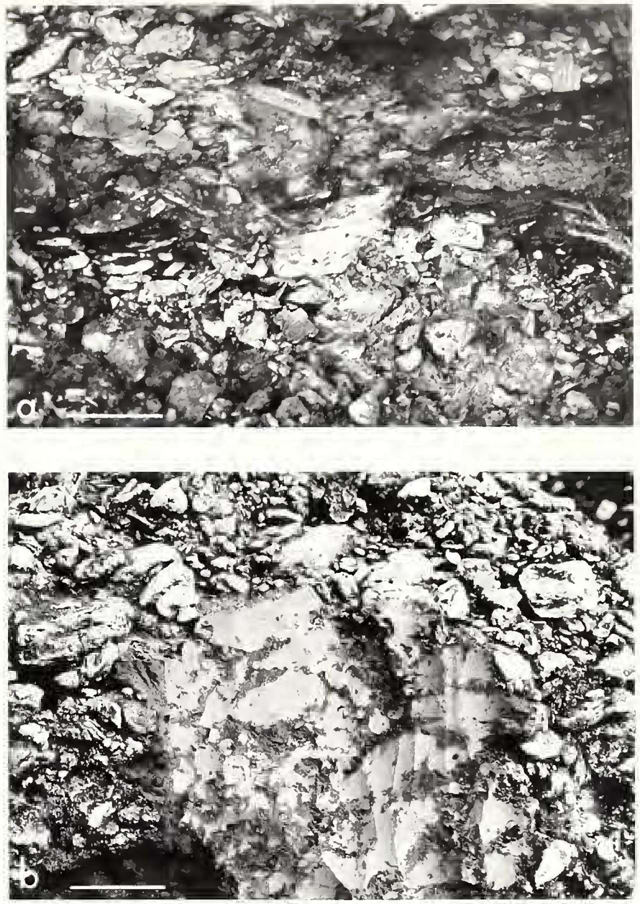

Figure 7. Representative clay-ball conglomerate that occurs in paleochannels within Member B of the Iñapari Formation. **a.** Variably colored clay balls of various sizes with silt and sand matrix; on Río Beni at Ciudad California (Fig. 1, loc. 13). **b.** Unaltered clay balls in well-sorted sand matrix; on Río Acre (Fig. 1), just upstream from the confluence of the Río de los Patos. Scale in each figure equals 10 cm.

river (e.g., Cavinas, Fig. 5b) by having a noticeably higher clay content to Members B and C, and by being much thinner. Both of these differences would be expected to occur at the limit of alluvial deposition in what we have come to regard as an environment of deposition similar to a broad delta.

The soil profiles visible in the river cutbanks of the Monte Realm north of its southern limits vary in a consistent, predictable manner with the height of the outcrop, a direct reflection of the length of time the soil has had to develop. The tops of the highest outcrops, here always at an elevation of about 20 m above the level of the river, are taken to represent the original surface formed by the depositional phase prior to the onset of the present cycle of erosion. These outcrops are everywhere characterized by a deep soil profile with a dark red color. Included in this soil profile is a hematitic concretionary zone about 0.5–1 m thick, lying about 2–3 m below the ground surface (Fig. 5b). These hematite deposits differ from the layers of hematite occurring lower in the section at the contacts between different lithologies. Instead of thick, solid layers, the hematite in the soil profiles occurs as agglomerations of small (less than 1 cm diameter) concretions that have in many places grown together. The dark red color of the soil profile was most pronounced at the concretionary zone.

This concretionary zone also appears in the thinner sections at the southern limit of the Monte Realm (Fig. 5a), but here it is thinner and does not lie as deep below the surface of the ground. This may reflect the higher clay content of the sediments in this region. Throughout the Monte Realm the A horizon of black humic material of the present soil profile only locally reaches a thickness of more than 15–20 cm.

As in the Sierra Realm, at the major outcrops the terrain extending back from the river's edge usually appears flat, a feature accentuated by the consistent placement of small settlements or villages on these high, isolated reaches of land with river access. The flat tops of the outcrops with incomplete sections indicate rivercut terraces, and within the Monte Realm there are many discontinuous terraces at approximately the same elevations above the river. Two pronounced

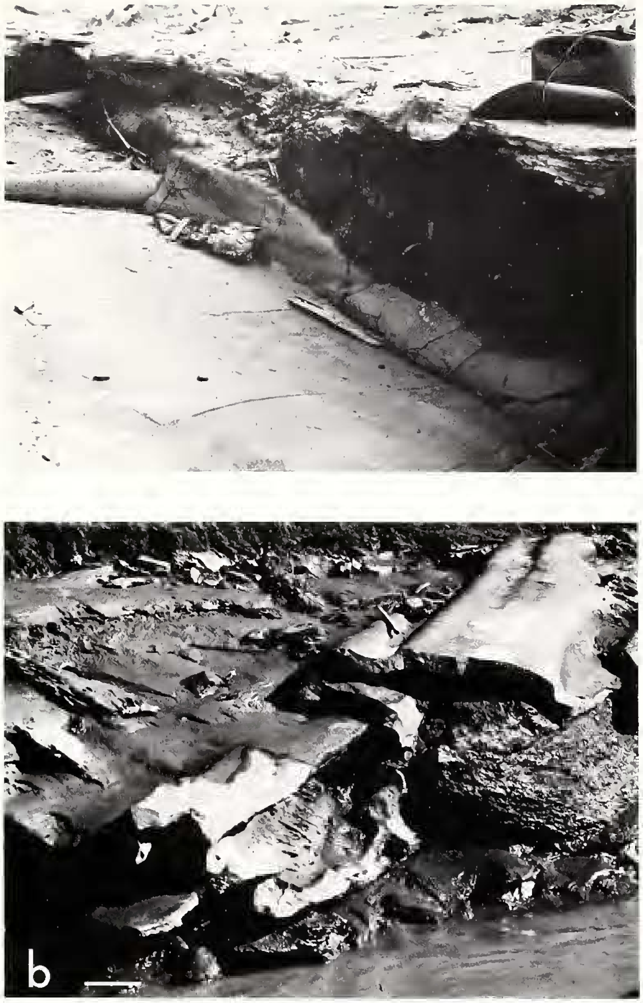

Figure 8. Thick layers of hematite separate Member A of the Iñapari Formation from overlying Member B. In **a,** the hematite layer is shown as it appears in a roadside ditch near the Río Buyuyo (Fig. 1), while in **b** the hematite layer is shown in cross section on the Río Beni near Barraca Rosario (Fig. 1, loc. 11). Note the similarity in surface ribbing and texture. The thickness of the partially mud-covered layer in **b** is 5–6 cm. This hematite layer was observed at almost every outcrop within the Monte Realm where the contact between Members A and B was exposed. Scale equals 15 cm.

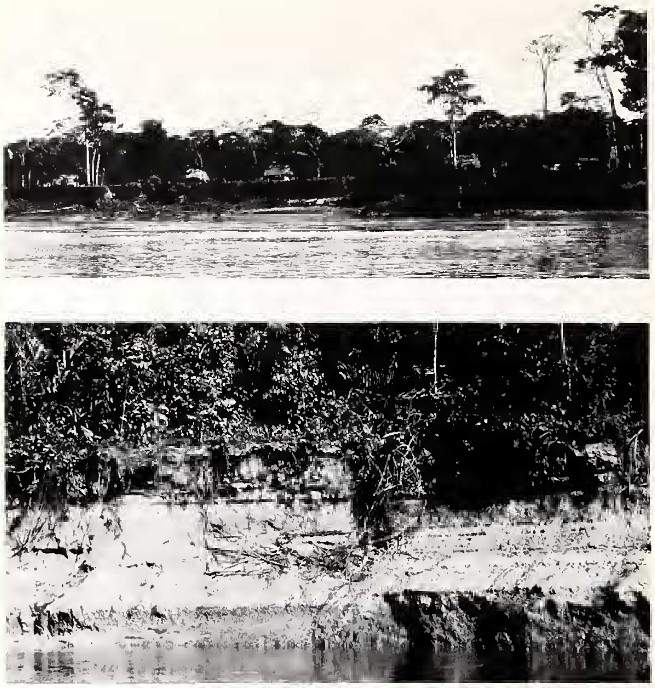

Figure 9. A river terrace at about 3–4 m above the level of the Río Beni. Above, showing cluster of homes on flat terrain; below, showing the 2–3 m of Member A of the Iñapari Formation capped by about 1 m of Recent alluvium. The dark zone at the base of the section reflects the dropping level of the river.

terrace levels occurring at several localities along the river are at about 9 and 15 m above the river. In addition to their different elevations, these two terrace levels differ in the soil profiles developed on them. At the 15 m level there is a 1–2 m thick, dark-red soil horizon similar to that seen at the top of the 20 m level, but no hematitic concretionary zone was present. The red color of the B horizon gradually faded into the C horizon and the original colors of the fine silts and sands of Member B or C. The soil profile developed at the 9 m level did not have as dark a red B horizon, nor was it as deep.

The lowest widespread terrace level north of the Río Madidi was at about 3–4 m. This low terrace consisted of an upper 1 m cap of dark silts and sands representing Recent flood deposits and a lower 2–3 m of the variegated red and yellow clays of Member A, into which this terrace had been cut (Fig. 9).

The terrain between Riberalta, on the Río Beni, and Guayaramerín, on the Río Mamore at the border with Brazil, is typical of that of a flat plain dissected by a developing dendritic drainage system. This terrain continues right up to the Río Mamore, but directly across the river loom the northernmost outlying hills of the Sierra dos Parecis, the westernmost range of the Brazilian Shield. Clasts of Shield rocks were found in deposits in Bolivia west of Guayaramerín, but they were not noted in deposits as far west as Riberalta.

CORRELATIONS

The outcrops along the Río Beni can be correlated with those that occur along the Río Acre (Campbell and Frailey, 1984, in press) (Fig. 10). The standard stratigraphic sequence (Fig. 11a), consisting of a basal unit of variably stratified clays with channel-fill deposits of sands and clay-ball conglomerates (Fig. 7b) capped by two thicker units of relatively unstratified, blocky silts and fine sands, is the same along each river. Similarly the three units are separated by disconformities, although along the Río Beni the contact between the upper two units is not always as clear as it is along the Río Acre. Paleochannels occur at the contact between Members B and C in some geologic sections of each river. Un-

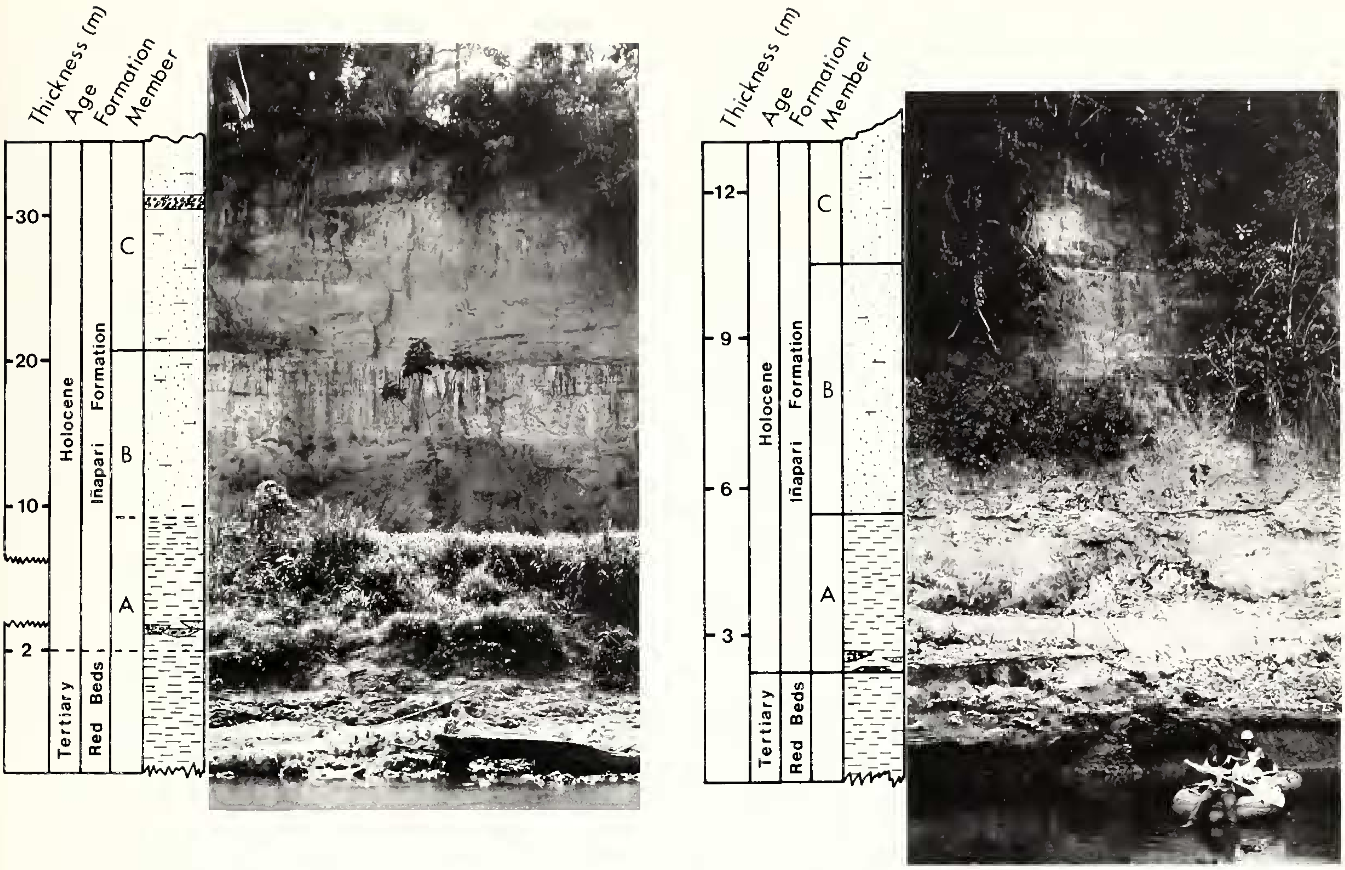

Figure 10. Two geological sections along the Río Acre, demonstrating their similarity to those seen along the Río Beni. **a.** Outcrop at San Lorenzo, about 30 air-km upstream from Iñapari, Peru, showing the various levels of the Iñapari Formation. Tertiary clays are exposed in the foreground. Member A of the Iñapari Formation is covered, but the contact between Members B and C is clear, as is the hematite concretionary zone near the top of Member C. This concretionary zone correlates with that seen in Fig. 5a, b. **b.** Partial section about 50 air-km upstream from Iñapari, Peru. The three members of the Iñapari Formation are clearly seen, as is the contact with the underlying Tertiary strata. The visible layer of hematite occurring at the contact between Members A and B of the Iñapari Formation correlates with that seen in Fig. 8a, b.

fortunately, along the Río Beni the contact between the basal clay unit and the underlying strata could not be seen, so it is not possible to say if the characteristic basal clay-pebble conglomerate occurring along the Río Acre, Río Buyuyo, Río Tahuamanu (Fig. 1), and Río Juruá also occurs along the Río Beni.

The three lithologic units observed along the Río Acre were referred by Campbell and Frailey (1984, in press) to the Iñapari Formation of ONERN (1977). Radiocarbon dates from four samples of wood from Member A of the Iñapari Formation taken at three different localities on the Río Acre ranged from 10,075 ± 150 yr B.P. to 5575 ± 105 yr B.P. (Campbell and Frailey, 1984, in press). We here include the Shiringayoc Formation of ONERN (1977) in the Iñapari Formation. The former was said to occur only along the banks of the rivers, with the latter occurring in broad areas between the rivers in the eastern part of the Departamento de Madre de Dios, Peru, on the frontier with Bolivia. Our field data indicate that the two formations are just one.

The hematite deposits observed along the Río Beni were not noted as a particularly significant feature along the Río Acre at the time of the fieldwork there, primarily because attention was focused on the fossiliferous basal clay-pebble conglomerate. However, these deposits do appear very clearly in field photographs taken at that time. The layered deposits of hematite at the contact between Members A and B of the Iñapari Formation can be seen in Fig. 10b, as well as a similarly prominent layer occurring at the contact between the Holocene and Tertiary strata. A sheet-like layer of hematite was also observed by the senior author in a roadcut leading to a bridge crossing the Río Buyuyo, due south of Porvenir and just east of the border with Peru (Fig. 8a). At this site, the layer of hematite separates the silts of Member B of the Iñapari Formation from the underlying clays of Member A, at the base of which occurs the characteristic clay-pebble conglomerate. The concretionary zone of hematite that occurs in the highest soil profiles along the Río Beni also appears in the complete sections along the Río Acre (Fig. 10a). It may be of interest to note that the nodules of hematite from this concretionary zone were being used as

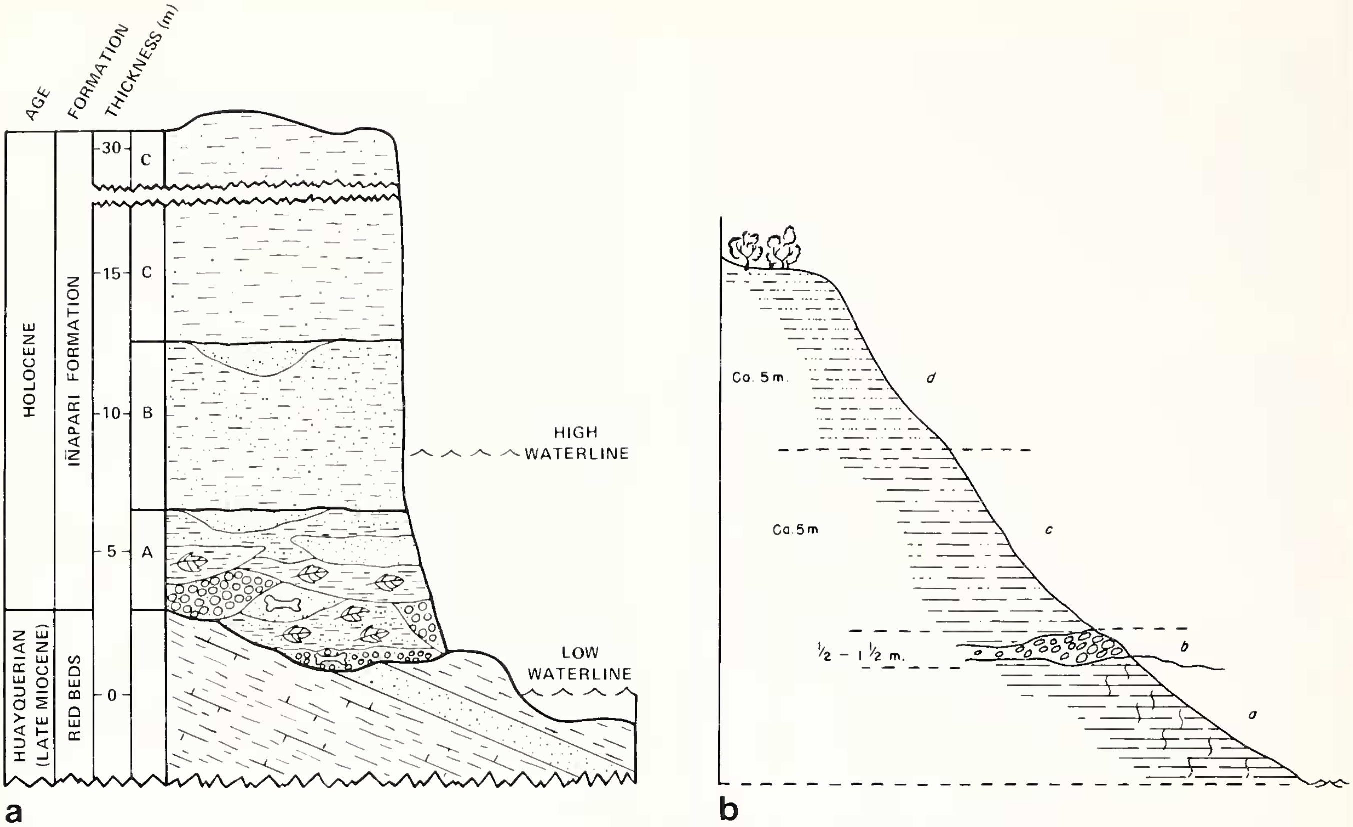

Figure 11. A comparison of the generalized geological sections along the **a** Río Acre and **b** Río Juruá. In **b**, the section at Pedra Preta, "a" represents Tertiary clays; "b" is a "heavy conglomerate" from which came Tertiary fossils; "c" is yellow-greenish clays and silts; and "d" represents buff fine sands and sandy silts. The contact between the different units was not clearly seen, according to the author. **a**, from Campbell and Frailey, 1984; **b**, from Paula Couto, 1978. A series of specific sections for the Río Juruá are presented in Simpson and Paula Couto, 1981.

"gravel" to surface the road running south from Cobija (on the Río Acre) to Porvenir (on the Río Tahuamanu) and the Río Buyuyo. ONERN (1977) states that iron concretions 1–3 cm in thickness occur in the Iñapari Formation (its Shiringayoc Formation).

Campbell and Frailey (1984, in press) correlated the outcrops exposed along the Río Acre with those found along the Río Juruá in western Brazil (Paula Couto, 1978, 1983; Simpson and Paula Couto, 1981) (Fig. 11b). If that correlation is correct and the deposits of the Río Beni correlate with those of the Río Acre, then the deposits of the Río Beni must also correlate with those of the Río Juruá. In that case, all of the Quaternary deposits of the Monte Realm in Bolivia may be referred to the Iñapari Formation. The Iñapari Formation, and the Monte Depositional Realm, must then have a minimum areal coverage extending from its source area somewhere in the Peruvian Andes to the Río Juruá to the northeast, and southeasterly to the Brazilian Shield in eastern Bolivia. Future fieldwork to demonstrate conclusively the broad areal extent of the Iñapari Formation is planned, but for the moment this interpretation is proposed as a working hypothesis.

The widespread deposits of the Monte Realm, i.e., the Iñapari Formation, were almost certainly deposited contemporaneously with those of the Sierra Realm. The stratigraphic and lithologic similarities between the three members of the two deposits also indicate that they must have been formed under very similar circumstances. It is possible that the two depositional realms merge into one in Peruvian territory to the northwest, in which case the deposits of the Sierra Realm will also be referable to the Iñapari Formation. The long distance separating the two depositional realms of the Río Beni, where riverbank outcrops are much lower than those within the depositional realms, indicates that the deposits of the lower Río Beni could not have been derived from the upper reaches of that river.

DRAINAGE SYSTEM ANALYSIS

It is possible to obtain a great deal of information regarding the physiography of northern Bolivia through an analysis of the present drainage system. For this we have used satellite photographs (Figs. 2, 3), a map of the Departamento de La Paz produced from satellite photographs (Instituto Geográphico Militar, 1981), and the only satellite-based topographic map presently available for any part of northern Bolivia (Río

Madre de Dios; Hoja SC 19-16, 1979, Instituto Geográphico Militar, La Paz).

From these sources and field observations it is possible to divide the course of the Río Beni east of the Andes into four regions (Fig. 2). Region I extends from Rurrenabaque through the Sierra Realm, and in it the Río Beni is initially characterized as a braided river and subsequently as an incised, meandering river. The braided portion is a result of the lateral release of water after being channeled through the narrow canyon cut through the front range. Where braided, the river bottom is covered by large cobbles and boulders. Just upriver from Buena Vista the various channels coalesce into one and continue as a single incised channel to a point just downstream from Altamarani, at the eastern limit of the Sierra Realm.

Region II encompasses the river system downriver from the end of Region I to approximately the Río Madidi. In this section the river is characterized as highly meandering, with oxbow lakes, cutoff meanders, and meander scars occurring almost everywhere on both sides of the main channel. The course of the river in the lower half of this section is delimited as a band of light gray cut through the surrounding dark gray (Figs. 2, 3). This color difference is explained by the presence of gallery forests growing on the natural levees formed by the river. The growth of these forests is aided by the slightly higher ground and better drainage afforded the terrain near the main river channel. A similar effect is noted along the Río Madidi and Río Biata, among others, that are also meandering rivers of the highest degree (Figs. 1, 2). The Río Biata can be seen to parallel the Río Beni almost to the front range of the Andes (Figs. 1–3), and evidence from satellite photographs suggests that its channel terminates in cutoff meanders of the Río Beni. During periods of flooding, the Río Biata must share the drainage of water coming through the front range at Rurrenabaque. The Río Beni may have become the main river draining the region because of the additional discharge it receives from the Río Madidi, a factor that may have allowed the Río Beni to deepen its channel at a faster rate than the Río Biata, even though it may have had to cut a longer channel through the Monte Realm.

Region III of the Río Beni extends from approximately the Río Madidi to Ciudad California (Fig. 1, loc. 13). In this region the river channel is incised, with long, straight stretches alternating with broad, gentle curves. The beginning of this section is just downriver from the southern limit of the Monte Realm, and the river is actively downcutting through the loosely consolidated Holocene sediments. It has not yet reached that stage of development where extensive lateral movements of the channel are possible; the channel is still contained within a very narrow valley and there are very few cutoff meanders or oxbow lakes.

In Region IV, from Ciudad California to Riberalta, the Río Beni is a meandering river, with abundant cutoff meanders, oxbow lakes, and meander scars. In contrast to Region II, with its natural levees built up above the surrounding terrain, the meandering river in Region IV is constrained within a narrow valley cut into the deposits of the Monte Realm. The meanders are large and widely spaced initially, but become smaller and more numerous approaching Riberalta, as do the cutoff meanders and oxbow lakes. The valley limits also become more clearly demarcated downstream. On satellite photographs the valley appears as a slightly darker gray, narrow band cutting through the surrounding light gray of the Monte Realm. A similar effect is perhaps more clearly seen for the valley of the larger Río Madre de Dios just to the north (Figs. 2, 3), where prominent scalloping of the valley walls clearly shows how the meandering river is enlarging its valley through lateral erosion.

Outcrops in the Monte Realm occur wherever the river channel curves into the constraining valley wall, undercutting it and forming a cliff. In Region III the outcrops are widely spaced, and all but the two northernmost occur on the eastern side of the river. In Region IV the outcrops are more closely spaced, and in many places alternate from one side of the river to the other as the meanders are deflected from alternate sides of the narrow river valley (Fig. 1). As would be expected, the valley of the Río Beni is broader and its channel more meandering downstream from the confluence of the Río Biata, although its development is clearly not equal to that of the Río Madre de Dios just to the north (Fig. 2).

After the juncture of the Río Beni with the Río Madre de Dios, the enlarged river channel continues its meandering course for a short distance, but gradually the meanders are extended into long curves and then into a relatively straight channel. This reflects the canyonization of the river as it leaves the unconsolidated, fine-grained Holocene sediments of the Amazonian lowlands and begins crossing the hard crystalline rocks of the Brazilian Shield. All the rivers of northern Bolivia drain into Brazil via the Río Madre de Dios, thus the rocks of the Brazilian Shield form the local base level for the entire region.

THE HOLOCENE HISTORY OF SOUTHWESTERN AMAZONIA

The available data are still too few to develop a definitive Holocene history of southwestern Amazonia, but they are sufficiently adequate for us to present our preliminary interpretations. While recognizing that major questions remain and that extensive fieldwork is still to be done, we feel that a picture is emerging.

One of the primary objectives of the geological survey of the Río Beni was to determine if three cycles of Holocene deposition and erosion were detectable in the alluvium deposited by the Río Beni after it exited the front range of the Andes and entered the essentially flat terrain of the eastern lowlands, the region we have termed the Sierra Depositional Realm. As we have described, three different lithologic units do occur in the Sierra Realm, and they are similar in stratigraphic sequence and lithologic composition to the three members of the Iñapari Formation occurring farther downstream in the Monte Depositional Realm and along the Río Acre. The three lithologic units of the two depositional realms are at present correlative only temporally; the deposits are not laterally contiguous anywhere in Bolivia (Fig. 3), and fieldwork in Peru is necessary to resolve their relationship to each other.

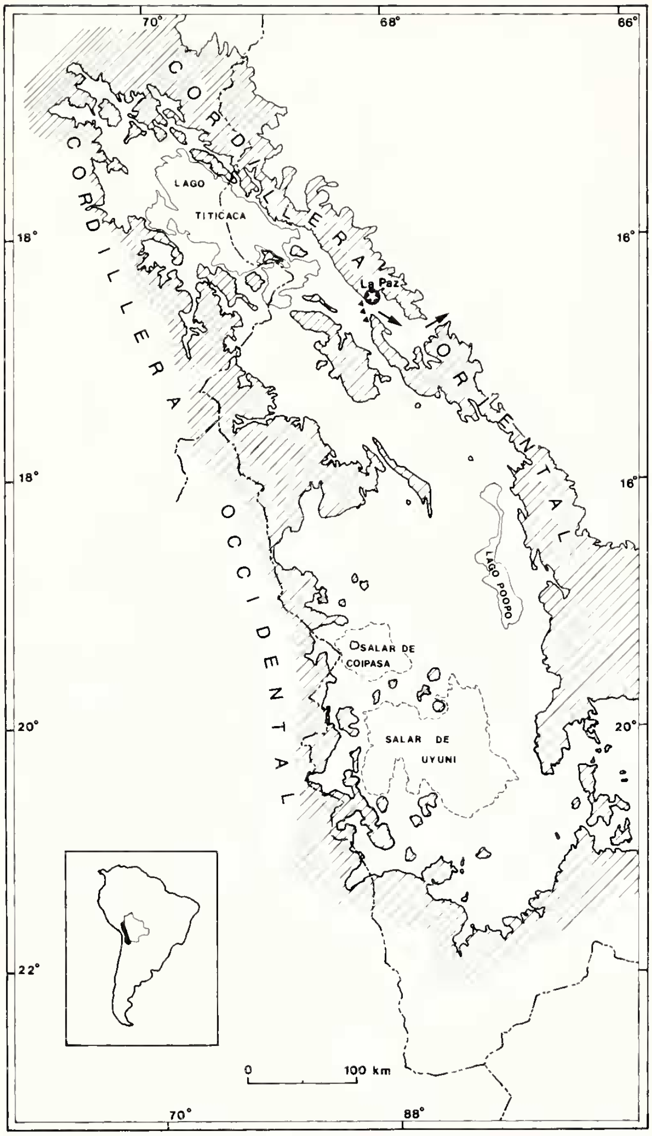

Figure 12. Map of the altiplano of Bolivia and southern Peru. The 4000 m contour line delimits the altiplano, within which lie two large lakes (Lake Titicaca and Lake Poopo) and two large dry salt lakes (Salar de Coipasa and Salar de Uyuni). The hatched area indicates elevations greater than 4000 m within and surrounding the altiplano. The triangles mark the most likely position for an ice dam, and the arrows indicate the direction of flow of the floodwaters out of the altiplano.

As noted earlier, however, the area covered by alluvium deposited by the Río Beni within the Sierra Realm is very small, less even than that immediately to the north and south where alluvium has accumulated from only the eastern slopes of the front range. To account for this lack of extensive alluvial deposits, we propose the occurrence of a catastrophic flood that (1) removed preexisting alluvial deposits from the area immediately east of the exit of the Río Beni from the front range, and (2) cleansed the principal intermontane valleys of the Río Beni of loose alluvium, thereby reducing the quantities of sediments available to form alluvial deposits after the flood. In addition, we propose that this flood (3) formed by scouring the series of depressions now occupied by lakes (Figs. 2, 3) that occur in a straight line northeast of Rurrenabaque, and (4) deposited the characteristic clay-pebble conglomerate that occurs as a basal component of the Holocene Iñapari Formation at least as far north as Cruzeiro do Sul, Brasil, on the Río Juruá.

As the source of the floodwaters, we propose a late Pleistocene lake sited in the Andean altiplano of Bolivia and Peru, the antecedent of Lake Titicaca (Fig. 12). The Andean altiplano is a broad, almost flat region occupying an area of almost 200,000 km^2 between the western and eastern cordilleras of the Andes. Elevations range from about 4000 m at its northern and southern limits to a low point near it center (Salar de Uyuni) of 3660 m. Lohmann (1970:754) referred to the formation of the altiplano peneplain as an "unexplained phenomenon," suggesting that possibly post-Pleistocene lacustrine and fluvial sedimentation redistributed Pleistocene glacial deposits to form the peneplain. He also stated that the altiplano was once continuous across the present La Paz valley, requiring that the erosion of the valley of the Rio de La Paz be a postglacial event. He calculated that approximately 20 km^3 of Quaternary and older material was removed from this valley during the past 10,000 year period, or that material was removed at an annual erosion rate of 2×10^6 m^3/yr (Lohmann, 1970). The mean annual precipitation for La Paz is 439 mm (Montes de Oca, 1983), which is clearly insufficient to account for the erosion required to form the valley. The elevation of the divide separating the altiplano drainage from that of the Río Beni, via the Río de La Paz, is only about 3970 m. The Altiplano has no external drainage, and its only potential outlet would be through the Río de La Paz, if the water were high enough.

The evidence from our preliminary field observations suggests that glacial ice coming out of the Cordillera Real (specifically, the Cordillera de La Paz where elevations reach over 7000 m) covered the eastern half of the altiplano. Reaching a ridge south of La Paz, this glacial ice could have formed a dam behind which collected glacial meltwaters. Alternatively, a glacial ice cap may have formed over the central ridge leading south from Lake Titicaca and the eastern altiplano, meeting the glacial cap coming off the mountains somewhere in the eastern altiplano. The occurrence of a widespread ice cap would help explain the formation of the altiplano peneplain, and topographic features such as numerous streamlined hills resembling rock drumlins suggest that in the eastern part of the altiplano there was ice flow toward the Lake Titicaca basin. This hypothesized glacial ice cover is in contrast to current views (Clapperton, 1983) that hold that during the last glaciation the mountain ice caps terminated in separate piedmont lobes and did not cover the altiplano.

Till deposits documented in the valley of the Río de La Paz to below 3500 m (Dobrovolny, 1956, 1962) indicate that the upper reaches of this valley were filled at various times during the Quaternary with glacial ice prior to the formation of the altiplano peneplain (Lohmann, 1970). Clapperton

(1979) gives a date of 3.27 myr for a till in the Río de La Paz valley that lies at an elevation of about 3900 m. Glaciers in the Cordillera de La Paz now reach elevations as low as 4800 m on the northeast flank of the range, and 5300 m on the southeast flank (Muñoz Reyes, 1977). The size differences of the existing glaciers is a result of the large precipitation differences that exist between the northeast and southeast flank of the mountain range.

The Río de La Paz is eroding headward into the altiplano via its small headwater tributaries, principally the Río Choqueyapu and Río Achocalla. But the upper reaches of the La Paz Valley do not assume the characteristic badland features consistent with headward erosion in a semiarid climate. Rather, the Río Choqueyapu ends headward in large U-shaped glacial valleys, whereas the Río Achocalla is a smaller stream that drains a huge bowl-shaped depression, the Achocalla Valley, with cliff-like rims that in places pose walls with shear drops of hundreds of meters. Except near presently existing stream channels, the bottom of this depression, while generally moderately to steeply sloping, is not eroded into the typical badland topography usually found in regions with poorly indurated Quaternary sediments and semiarid climates. The Río Choqueyapu and the Río Achocalla are clearly underfit streams (fide Dury, 1964), and we find that the Achocalla Valley bears a striking resemblance to the plunge pool of a giant waterfall (see Ahlfeld and Branisa, 1960: fig. 56).

Glacial lakes are known to have occurred in the altiplano, and three have been named (e.g., Ahlfield and Branisa, 1960; Bowman, 1909; Lavenu, 1981; Montes de Oca, 1983; Servant, 1977; Servant and Fontes, 1978). The history of these lakes, however, is not very clear. Lake Ballivián existed in the northern part of the altiplano and is said to have been 50 percent larger than Lake Titieaca, thus covering an area of 12,600 km^2. It left deposits at an elevation of 3850 m. No exact age for this lake has been determined. Lake Minchin existed in the southern part of the altiplano and covered an area of 60,000 km^2 at an elevation of 3760 m. Its period of maximum extension has been put at before 27,500 yr B.P., based on radiocarbon dates of calcareous deposits. Lake Tauca covered an area of 43,000 km^2 at an elevation of 3720 m in the southern altiplano, and is said to have existed from 13,000 to 10,000 yr B.P. Lake Titicaca presently covers about 8400 km^2 at an elevation of 3810 m in the northern part of the altiplano. Clapperton (1983) and Lavenu et al. (1984) report lake levels even higher than 3850 m, with the latter describing newly discovered lake features at an elevation of 3950 m. This is 140 m above the present level of Lake Titicaca and only 20 m less than what would be required for a lake to overflow the lip of the altiplano. Although each of the glacial lakes is said to have existed at different interglacials, is there a possibility that perhaps they represent instead stillstands of a single great lake that covered all of the altiplano?

We propose that just such an extensive glacial lake did form after 14,000 yr B.P. when glacial ice in the Andes receded rapidly (Emiliani et al., 1975; Mercer, 1977). Unless blocked by glacial ice in the western altiplano, this glacial lake may have extended southward to cover an area in excess of 150,000 km^2. As the lake grew in size it overflowed the edge of the glacial ice in the region of La Paz, and the overflowing water began forming the large horseshoe-shaped basin with high, vertical sides which is the Achocalla Valley. At some point the system broke down and a large portion of the remaining lake waters drained catastrophically. Perhaps this resulted from a 200 m uplift of the altiplano northeast of La Paz cited by Lohmann (1970:754) as possibly being contemporaneous in part with the Holocene erosion of the valley of La Paz.

Once the ice dam was breached, the water would have cascaded down the narrow intermontane valley of the Río de La Paz and into the Río Beni, dropping from an elevation of about 4000 m to less than 250 m in a distance of approximately 350 river-km. At several points in the eastern cordilleras the Río Beni flows through very narrow canyons cut transversely through high ridges. These narrow canyons would have restricted the rate of flow, and the water would have formed temporary lakes filling numerous intermontane valleys. The narrow canyon of the front range, which is only about 200 m wide, is just such a constriction. Features visible on satellite photographs, such as what appear to be high plateaus with large, abandoned river channels and possibly giant ripple marks downstream from an anticline composed of Tertiary rocks, suggest that the large valley just west of the front range (Fig. 2, with large white cloud in center) was indeed filled with water. This flooded valley would have maintained great hydraulic pressure on the floodwaters flowing through the narrow canyon of the front range. And because the valley would have served as a giant reservoir, the flow through this canyon onto the lowlands may have continued for some time.

The floodwaters would have emerged onto the flat lowlands as a gigantic, high-pressure stream, much like water passing through a sluice gate in a dam. Carrying away any alluvial deposits in its path, the narrow stream of water scalloped out the chain of rectangular depressions now occupied by lakes that so prominently form a straight line pointing away from the canyon exit (Figs. 1–3). A well-known alternative explanation for this chain of lakes is based on presumed fractures of basement rocks (Montes de Oca, 1983: 152), but it is difficult to see how basement fracturing could be expressed through a surficial cover of Recent alluvium in an area that is regularly inundated by floodwaters and is without recorded seismic activity. Even Laguna Rogaguado (Fig. 3) and the lakes surrounding it, which lie to the northeast of and are in line with the chain of rectangular lakes, may have been formed by the erosive powers of this stream of water.

On satellite photographs there is a strong hint of an alluvial fan of standard shape with its center near the Río Beni and extending northeastward in a large semicircle. A large, dark wedge-shaped slice is removed right of center. It should be noted that although the present course of the main channel of the Río Beni is at an angle to the chain of lakes, the structure of the canyon through the front range is such that a high volume of water would be forced in the direction of

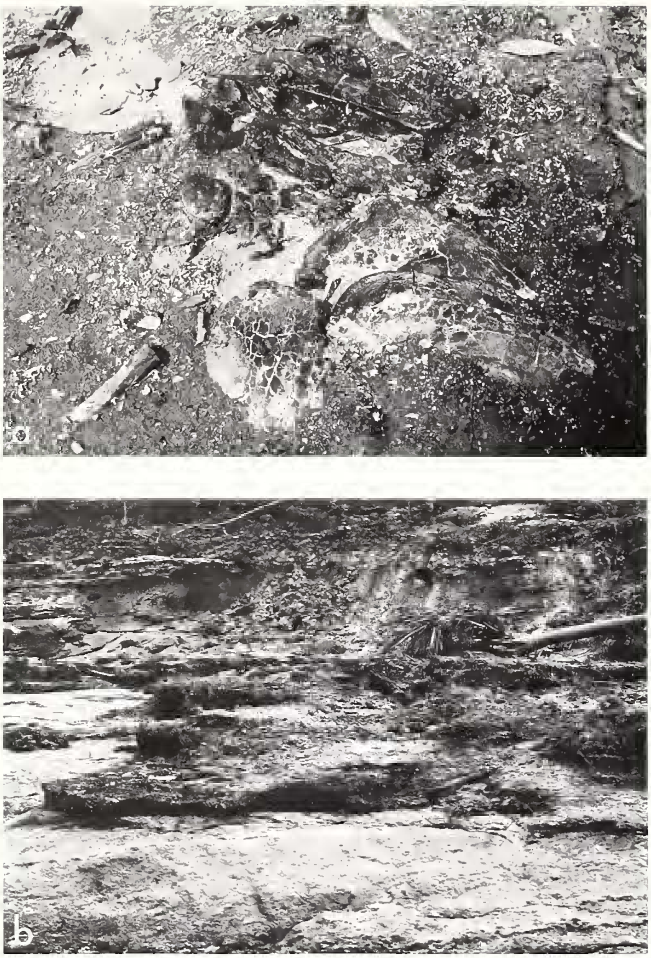

Figure 13. **a.** The partial associated skeleton of a toxodont lies in situ in Tertiary (late Miocene, Huayquerian) clays along the Río Acre. The two lower jaws, a scapula, and several leg bones are visible. **b.** In the foreground, the clay-pebble conglomerate, or Acre Conglomerate Member of the Iñapari Formation, is seen resting on Tertiary clays at a locality on the Río Acre. Channel deposits and stratified clays of Member A of the Iñapari Formation can be seen in the background.

the lakes (Fig. 2). This course is followed today by one of the braided river channels before it turns north-northeastward and joins with the main river channel. After exiting the front range, the floodwaters would have followed a general northward path as a sheet flood, disrupting existing drainage systems.

There is no reason to assume that the pre-Holocene Quaternary drainage system of southwestern Amazonia bore any resemblance to that of the area today. In fact, it may be expected that the pre-Holocene drainage of northern Bolivia flowed due north over the relatively soft Tertiary clays, skirting the western edge of the Brazilian Shield rather than cutting a canyon through its hard crystalline rocks, much like the Ríos Itenez and Mamore do in part today. If such were the case, the later deposition of the Iñapari Formation created a dam, closing off direct northern drainage from Bolivia and forcing the rivers to exit Bolivian territory by crossing over the Brazilian Shield, the course now followed by the Río Madre de Dios before it becomes the Río Madeira and drains into the Río Amazonas. The Iñapari Formation, extending as a blanket over older strata from the Peruvian Andes to the Brazilian Shield, may be effectively covering all evidence of pre-Holocene Quaternary drainage systems.

Racing northward, the sheet flood hypothetically stripped the soil from the surface, exposed the underlying unaltered Tertiary deposits, and deposited the characteristic basal clay-pebble conglomerate of the Iñapari Formation. Prior to the deposition of the Iñapari Formation the general elevation of the region would have been at least 20–35 m lower than today and the terrain was probably even more level than at present. Therefore, it can be assumed that the rivers were at least as easily susceptible to flooding as they are at present, and that any sheet flood could not possibly have been contained in such shallow river valleys.

Of special importance is the probability that in its short-lived passage the sheet flood deposited the characteristic clay-pebble conglomerate with its reworked Tertiary fossil vertebrates and wood that occurs only at the base of the Holocene deposits. Simpson and Paula Couto (1981) and Frailey (1980) remarked on the unusual conditions of the fossil vertebrates in this basal Holocene deposit. Some of the fossils are very water worn, indicating long distance transport, but others cannot have been transported far, or reworked extensively. For example, Simpson and Paula Couto (1981:19) state that "... glyptodont scutes may have been worn almost formless but may also occur in large, unworn clusters in which the plates have not been separated at sutures; ...." They also reported finding no associated fossil skeletons. Campbell and Frailey (in press) and Frailey (1980) reported on rich fossil localities on the Río Acre where they did find associated vertebrate skeletons, but these were in situ in the Tertiary strata, not part of the clay-pebble conglomerate (Fig. 13a). They were, however, at the same physical level relative to the river channel as the clay-pebble conglomerate (Fig. 13b).

We propose that the Tertiary fossils in the clay-pebble conglomerate were reworked and redeposited near their point of origin by the churning sheet flood, and that the reported differences in wear of the fossils occurred at the time of their primary deposition. In the case of the aforementioned glyptodont scutes, the well-worn, isolated scutes may have undergone long distance transport prior to their fossilization in the Tertiary, while the partial carapaces composed of many scutes were fossilized in the Teriary without being transported far, if at all. Permineralized as a block, the partial carapace was perhaps too strong to be broken up into individual scutes by the passing floodwaters before they were redeposited a short distance from their original site. But at the same time, elements of associated fossil skeletons present in the Tertiary deposits would probably have been dispersed before being redeposited in the clay-pebble conglomerate.

Campbell and Frailey (1984, in press) proposed a flooding mechanism to remove the soil from the Tertiary strata and deposit the clay-pebble conglomerate noted along the Río

Acre and Río Juruá, but at the time they did not have a single catastrophic flood in mind. Instead they proposed that general massive flooding, sparked by rapid melting of Andean glaciers at the end of the Pleistocene (Emiliani et al., 1975) and occurring over a short time period, produced the observed geological features. A single catastrophic flood is a more parsimonious hypothesis to explain the formation of the clay-pebble conglomerate, as well as other geological features in the region. It is necessary, however, to determine where the coarse debris and large bedform features expected from such a flood are located. It is probable that the evidence necessary to document the flood will be found in the mountains rather than in the forested and swampy lowlands where Holocene deposits may be covering all but a few traces of the erosional and depositional features of the flood. The search for such evidence is in progress, but until it is available we recognize the speculative nature of our proposal. Catastrophic flooding of enormous scale resulting from abrupt draining of glacial lakes has been recorded elsewhere (Baker and Nummedal, 1978; Bretz, 1923; Bretz et al., 1956; Malde, 1968), and large-scale catastrophic floods have even been proposed to explain certain geological features on Mars (Baker, 1978).

A hypothesis for the deposition of the three members of the Iñapari Formation was presented by Campbell and Frailey (1984, in press). The hypothesis of a catastrophic flood would modify their interpretation of events slightly in that the fossiliferous basal clay-pebble conglomerate of Member A of the Iñapari Formation is now seen as a unique deposit formed at a specific time prior to the deposition of the remainder of Member A. To recognize this distinction we propose that this unit be named the Acre Conglomerate Member of the Iñapari Formation, after the river where its distinctiveness was first clarified. The type locality is on the south bank of Río Acre, 2 km east of the confluence of Río de Los Patos.

Following the passage of the sheet flood, sediments that formed the Iñapari Formation were washed eastward out of the Peruvian Andes by the meltwaters of the disappearing glaciers. More field data are required to pinpoint the exact source of these sediments. Large-scale seasonal flooding lasting from about 10,000 yr B.P. to about 5000 yr B.P. was proposed by Campbell and Frailey (1984, in press) to account for the highly channeled, variably unstratified and stratified clay deposits of Member A of the Iñapari Formation. This proposal was based in part on the model developed by Kutzbach (1981) to explain early Holocene pluvials in Eurasia.

Rather specific conditions must have existed for the relatively pure clays of Member A of the Iñapari Formation to be deposited over such a broad region. This probability is increased by the fact that Member A in the Sierra Realm is also a channeled clay deposit. It could be expected that the sediment load of rivers entering the Amazonian lowlands had a sizable clay fraction, a feature not unusual for waters draining large areas of recently exposed glacial deposits in high mountains. However, the deposition of clays requires essentially still water. This indicates that inundated areas in the region drained slowly, except in restricted zones where the paleochannels of silts, sands, and clay-ball conglomerates (Fig. 7) indicate fairly weak to strong current flow.

One possible cause of large-scale still water may have been that the preexisting, i.e., pre-Holocene, drainage system was blocked by sediments or otherwise disrupted by debris from the catastrophic sheet flood as described above. This would not be unexpected if, as suggested, the terrain were more flattened than today. Taken together with the increased seasonal precipitation and more rapid and extensive snowpack melt proposed by Campbell and Frailey (1984), an essentially nonexistent drainage system throughout southwestern Amazonia could have accentuated the development of broad, anastomosing rivers with minimal gradients and extensive swamplands susceptible to ready inundation. These conditions would lead to the deposition of widespread clay deposits.

After a change in climate about 5000 yr B.P., and a subsequent period of erosion, Members B and C of the Iñapari Formation were deposited. The lithologic similarity between these two units indicate that they were deposited under similar conditions, and their lithologic differences from Member A, i.e., silts and fine sands instead of clays, indicate that these conditions were different from those that prevailed earlier in the Holocene. The break between the last two periods of deposition was placed at about 2800 yr B.P., under the assumption that the break in deposition represented a significant climatic change that could be expected to correlate with Holocene climatic events recorded elsewhere (Denton and Karlén, 1973; Fairbridge, 1976; Mercer, 1977; Wendland and Bryson, 1974). The worldwide climatic anomalies experienced during 1983 (Philander, 1983a, b; Gill and Rasmusson, 1983) clearly demonstrated how, if not why, such correlations may occur.

The northward drainage of the eastern lowlands of Bolivia must have been completely blocked by the time Member C of the Iñapari Formation was deposited, leaving much of the region south of the Monte Realm waterlogged until drainage was established over the Brazilian Shield. The drainage pattern that has emerged since that time is one of a series of major rivers, often flowing for long distances in roughly parallel courses (Figs. 1, 3), then converging in the northeastern corner of the country and crossing the Brazilian Shield. Secondary drainage follows a classic dendritic pattern, indicating uniformity of substrate and lack of structural control.

The imposition of the drainage system upon the Iñapari Formation can be seen rather clearly in the regions of the Río Beni described earlier. These regions represent different stages of development, or maturity, of the river. Region III is typical of a young river that is actively eroding downward, while Region IV reflects a more mature stage, with a meandering channel developing and occupying a broader valley. A similar effect is reflected in the valley of the Río Madre de Dios, where, of that segment of the river course shown in Fig. 3, the eastern half is far more meandering within a more clearly developed valley than the western half.

The highly meandering nature of Region II of the Río Beni is a result of the Iñapari Formation acting as a local base level for the river, just as the crystalline rocks of the Brazilian

Shield act as the local base level downriver from the confluence of the Río Beni and Río Madre de Dios. The natural levees so prominent in Region II result from deposition of sediment as the river overflowed its low banks during periods of flooding and flowed laterally, unrestrained by valley walls. Such flooding is probably accentuated by the fact that in Region III the river enters into a narrow valley that can only accommodate a portion of the river's discharge during periods of flooding.

The river terraces noted along the Río Beni within the Monte Realm probably resulted from temporary local base levels established and then eroded away in the course of the river over the Brazilian Shield. That terraces of approximately similar height above the river can be found at many localities along the river within the Monte Realm suggests that some of the temporary local base levels lasted for a significant period of time. As one bit of evidence for local control over the formation of these terraces we cite the absence of a comparable series of terraces along the Río Acre. In fact, very few places along the Río Acre upstream from Cobija can be considered as river terraces.

IMPLICATIONS FOR OTHER RESEARCH

Clearly, more documentation of the proposed catastrophic flood and further data regarding the integrity of the Iñapari Formation are required before any definitive statements can be made about the Quaternary history of southwestern Amazonia. Nevertheless, the geological data from the Río Beni reemphasizes the importance of studies of the Quaternary geology of Amazonia to other fields of research as noted by Campbell and Frailey (1984, in press). For example, one important question we can raise is, just how old are the tropical Amazonian forests as we know them? The traditional view is that the forests are millions of years old (e.g., Abelson, 1983). The newly popular hypothesis of "tropical forest refugia," which holds that some areas of forest are very old, having survived intact during the Pleistocene, while surrounding areas of forest were converted to savannas by climatic changes (see papers in Duellman, 1979, and Prance, 1982) is based almost entirely on the distributions of plants and animals. Without supporting geological data, any interpretations of the age of Amazonian ecosystems must be considered speculative.

As another example we may cite the use of the "tropical forest refugia" hypothesis to determine the location of areas of high priority or conservation (Lovejoy, 1982). The Río Acre region is proposed by some (e.g., Brown, 1982) to have been a tropical forest refugium during the Pleistocene, and therefore remained as a stable forest community into the present. But this proposal is untenable given the possibility that the region was swept clear by a passing flood and because the region is covered by the Holocene Iñapari Formation, the youngest deposits of which may be less than two thousand years old. We agree that there is a good probability that tropical forest refugia existed during the Pleistocene, and that these areas should receive priority status regarding conservation. But it is critical for these areas to be delimited first on a geological, not a biological, basis.

In this regard, it is interesting to note that the greatest avian species diversity for any locality in the world, over 500 species, is to be found in the Tambopata Reserve of Peru (Parker, 1982), located just 210 km south of the Río Acre and 150 km southwest of the Río Buyuyo site. Campbell and Frailey (1984, in press) suggested that there is a good probability that this reserve, at an elevation of only 260 m, is resting on surficial deposits of the Iñapari Formation. If so, the high diversity recorded there cannot be a result of long-term environmental stability.

Similarly, studies of such disparate topics ranging from Amazonian biogeography to pedology cannot move forward without a better understanding of the geological history of the region. Unfortunately, a review of a recent important symposium on Amazonia (Donsereau, 1984) held no mention of Quaternary geology, an indication of how the subject is neglected. This can only be to the detriment of all fields of research relating to Amazonia that are, or should be, dependent on a thorough understanding of regional geological history.

Even research into the paleoethnography of Amazonia is incomplete without basic studies of late Quaternary geology. Extensive flooding and depositional events in southwestern Amazonia must have had a dramatic impact on Amerindians in the region. These rather severe environmental changes may explain the absence of early Holocene archaeological sites in Amazonia (Meggers, 1979, 1982), and the fact that few sites in Amazonia with *terra preta* soils are reliably dated beyond about 2000 yr B.P. (Eden et al., 1984). The geological events proposed and described above may also be the basis for some of the myths of Amerindians that speak of periods of great floods (Meggers, 1982). One such myth, said to originate with the "Huni Kui" tribe of the Amahuaca Indians that lived in southwestern Amazonia in the region between the Río Acre and Río Juruá may even be an "eyewitness" account of the catastrophic flood we have proposed:

> In the dim and ancient past beyond recall, when man could still talk with animals, our people had many villages and lived in peace with abundance of everything. They lacked nothing and lived in happiness on the sandy shore of the great river where the water meets the sky.
>
> One day there came a great storm, worse than ever before. It rained day and night. Everything stopped and the people went to their houses. Thunder and lightning came with a terrible wind, destroying the houses.
>
> The sky broke and fell down. The earth went up into the sky. Everything died except some crabs in a hole. No other life remained. The land became sky; the sky, land. Then the sky returned to its place and took the spirits of the dead with it up into the sky. There the spirits lived happily, but on the earth there was nothing but a few crabs. [Lamb, 1974:120–121]

SUMMARY

A geological survey along the Río Beni in northern Bolivia has demonstrated the existence of Quaternary sediments that were deposited in two widely separated depositional realms: the Sierra Realm, with sediments derived from the Bolivian Andes; and the Monte Realm, with sediments derived from the Peruvian Andes. The deposits in the two depositional realms were probably deposited contemporaneously, and the same sequence of deposits occurs in both: a lower unit of channeled, variably stratified clays and two upper units of blocky silts and fine sands.

The sediments of the Monte Realm are referred to the Iñapari Formation of ONERN (1977), a series of alluvial deposits assigned to the Holocene by Campbell and Frailey (1984, in press). The channeled, variably stratified clays of Member A of the Iñapari Formation were deposited from about 10,000 yr B.P. to about 5000 yr B.P. Following a period of erosion, and a change in the environment of deposition, the blocky silts and fine sands of Members B and C of the Iñapari Formation were deposited. A disconformity separating these two members represents a period of erosion, the age of which is put at about 2800 yr B.P. The Iñapari Formation appears to cover at least that part of southwestern Amazonia extending from the Peruvian Andes northeast to the Río Juruá (to Cruzeiro do Sul, Brasil) and southeast to the Brazilian Shield.

The deposition of the Iñapari Formation formed a dam across northern Bolivia, forcing the regional drainage northeastward, over the crystalline rocks of the Brazilian Shield. The imposition of the present drainage system upon the Iñapari Formation is reflected in the varying stages of development of the river valleys in northern Bolivia, with the course of the Río Beni east of the Andes being divisible into four clearly distinct regions.

A catastrophic flood resulting from the sudden draining of glacial Lake Titicaca is proposed to account for (1) the lack of alluvial deposits extending eastward from the front range of the Andes at the point where the Río Beni enters the flat lowlands; (2) the prominent chain of lakes extending northeastward in a straight line from the opening of the Río Beni onto the flat lowlands; and (3) the deposition of the characteristic clay-pebble conglomerate with Tertiary fossil vertebrates and wood, herein named the Acre Conglomerate Member of the Iñapari Formation.

The documentation of Holocene deposits over wide regions of southwestern Amazonia has broad implications for numerous fields of research, including such disparate fields as biogeography, conservation, ecology, hydrology, pedology, and paleoethnography.

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